U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-299 296

# Relating Data to Effects, Standards and Source Reductions

(U.S.) Environmental Sciences Research Lab, Research Triangle Park, NC

1978

"Relating Data to Effects, Standards, and Source Reductions,"
by Ralph I. Larsen, pp. 329-338 in

PB 299296

# Quality Assurance Practices For Health Laboratories

Stanley L. Inhorn, M.D.
*Editor*

**Publication Office:**

American Public Health Association
1015 Eighteenth Street N.W.
Washington, DC 20036

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Interdisciplinary Books & Periodicals
For the Professional and the Layman

TECHNICAL REPORT DATA
*(Please read Instructions on the reverse before completing)*

PB299296

| 1. REPORT NO. | 2. | 3. RECIPIENT'S ACCESSION NO. |
|---|---|---|
| EPA-600/J-78-138 | JOURNAL ARTICLE | |

| 4. TITLE AND SUBTITLE | 5. REPORT DATE |
|---|---|
| RELATING DATA TO EFFECTS, STANDARDS, AND SOURCE REDUCTIONS | 6. PERFORMING ORGANIZATION CODE |

| 7. AUTHOR(S) | 8. PERFORMING ORGANIZATION REPORT NO. |
|---|---|
| Ralph I. Larsen | |

| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | 10. PROGRAM ELEMENT NO. |
|---|---|
| Same as 12 | 1AA603 |
| | 11. CONTRACT/GRANT NO. |

| 12. SPONSORING AGENCY NAME AND ADDRESS | 13. TYPE OF REPORT AND PERIOD COVERED |
|---|---|
| Environmental Sciences Research Laboratory - RTP, NC<br>Office of Research and Development<br>U. S. Environmental Protection Agency<br>Research Triangle Park, NC 27711 | 14. SPONSORING AGENCY CODE<br>EPA/600/09 |

15. SUPPLEMENTARY NOTES

REFERENCE: In: Quality Assurance Practices for Health Laboratories, S. L. Inhorn (ed.). American Public Health Association, Washington, DC. 1978. p.329-338

16. ABSTRACT

Air Quality data are needed in many phases of air management. Air management itself involves the following 12 steps:

1) Determine the effects of various pollutant concentrations and exposure durations on people, plants, and property. 2) Decide which effects to prevent. 3) Select air quality goals or standards that will prevent these effects. 4) Measure and evaluate ambient air pollutant concentrations. 5) Calculate overall source reductions needed for an area to achieve selected ambient air quality goals. 6) Measure or estimate emissions from each source type in an area. 7) Decide how much each source can be permitted to emit and still achieve the desired ambient air quality goals, considering costs, social changes, and so forth. 8) Select or develop means for achieving the necessary source reductions. 9) Decide the date by which each source type should be controlled. 10) Set emission standards. 11) Enforce emission standards. 12) Continue monitoring sources and the ambient atmosphere to ensure that adequate air quality is being achieved.

Air quality data are needed in Steps 1, 3, 4, 5, 7, and 12. The purpose of this section is to describe briefly how air quality data can be used to meet these needs; the references cited provide more detailed information.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| * Air pollution<br>* Data<br>* Relations(mathematics)<br>* Standards<br>* Sources | | 13B<br>12A |

| 18. DISTRIBUTION STATEMENT | 19. SECURITY CLASS *(This Report)* | 21. NO. OF PAGES |
|---|---|---|
| RELEASE TO PUBLIC | UNCLASSIFIED | 12 |
| | 20. SECURITY CLASS *(This page)* UNCLASSIFIED. | 22. PRICE A02-A01 |

EPA Form 2220-1 (9-73)

4) $O_2$ flow (flowmeter with analogue output)
5) Sample inlet (to calibration or sample manifold)
6) Sample inlet flow (see No. 4)
7) Calibration source gas (ON/OFF)
8) Calibration dilution air (ON/OFF)
9) Calibration dilution air (ON/OFF)
10) Calibration dilution air flow (see No. 4)
11) Calibration manifold exhaust blower (ON/OFF)
12) Monitoring instrument temperature (analogue signal)
13) Instrument response for NO (analogue)
14) Instrument response for $NO_2$ (analogue)
15) Instrument response for $NO_x$ (analogue)

The first 12 items relate information about the validity of the last 3 items.

Zero- and span-calibration checks are taken daily. Wherever these identify out-of-tolerance conditions, all data since the last calibration check are deleted from the system.

To complete the machine validation, Items 13, 14, and 15 above are subjected to statistical analyses for locating points out of the range defined by immediately preceding points, and these are further subjected to trend analysis output.

These validation techniques are of two general types, and they can also be applied to data entered manually. These validations are needed to check characteristics of the data or a history of the sampling site.

In checking the data, the most common approach is to check one of three items: (a) Identify all values that exceed a user-supplied maximum value; (b) identify all values that are less than a user-supplied minimum value; (c) identify all values that differ from the preceding value by a certain user-supplied number. A check could also be made for consecutive numbers with the same value, although this is not done as often as the three checks listed above.

In examining historical data from a sampling site, there are two common checks: (a) Compare the current-quarter statistics (mean, standard deviation) with the same statistics for the previous quarter, and identify where they differ by a user-supplied value or percentage; (b) for pollutants that exhibit seasonal variation, compare the current-quarter statistics with the same statistics for the same quarter of the previous year (or years).

Outliers identified by the above checks can then be examined carefully by checking with personnel or records, examining meteorological data, or checking recent changes in the environment of the sampling site. If no obvious error is detected, the values should be left in the system.

### Presentation

The previous discussions of data processing have been directed toward minimizing the number of errors entering the system, identifying errors already in the system, and preventing inadvertent destruction of data in the system. The last consideration is how to present data clearly to avoid misinterpretation.[29]



Presentations should provide useful aerometric information rather than raw data. To this end, all codes should be identified by their English-language equivalent. Air quality data are often of such volume that they should be summarized before being reported. Before any statistics are calculated, criteria should be applied to assure that the resulting statistic will be representative. For continuous data in the SAROAD system, no statistics are calculated for quarters or years unless 75 percent or more of the values are present. Since daily data are on a random or systematic schedule, criteria are applied that check both the total number of values and the distribution of values throughout the reporting period. There should be some way to identify that data exist for a site even if they do not meet criteria.

The other problem in summarizing data is handling values that are below instrument-detectable limits. In calculating any geometric statistics, zero values cannot be used if logarithms are to be taken. The approach in the SAROAD system is to substitute one-half of the minimum detectable limit for each zero value prior to calculating any statistics. This substitution is only made when less than 25 percent of the measured values are below the detectable minimum. To maintain consistency, the same value is used from year to year unless the minimum detectable level changes by an order of magnitude.

Presentation format varies with individual agencies. Programs plotting values, listing summaries, counting violations, and computing frequency distributions are the most common presentations, but regardless of format, the above suggestions should help to improve the clarity of the report.

EPA-600/J-78-138 - JOURNAL ARTICLE

## Relating Data to Effects, Standards, and Source Reductions

Air quality data are needed in many phases of air management. Air management itself involves the following 12 steps:[30]

1) Determine the effects of various pollutant concentrations and exposure durations on people, plants, and property.
2) Decide which effects to prevent.
3) Select air quality goals or standards that will prevent these effects.
4) Measure and evaluate ambient air pollutant concentrations.
5) Calculate overall source reductions needed for an area to achieve selected ambient air quality goals.
6) Measure or estimate emissions from each source type in an area.
7) Decide how much each source can be permitted to emit and still achieve the desired ambient air quality goals, considering costs, social changes, and so forth.
8) Select or develop means for achieving the necessary source reductions.
9) Decide the date by which each source type should be controlled.
10) Set emission standards.
11) Enforce emission standards.
12) Continue monitoring sources and the ambient atmosphere to ensure that adequate air quality is being achieved.

Air quality data are needed in Steps 1, 3, 4, 5, 7, and 12. The purpose of this section is to describe briefly how air quality data can be used to meet these needs; the references cited provide more detailed information.

## Air pollutant effects versus exposure duration

The exposure time needed to cause a particular pollutant effect depends on the type of effect, as indicated in Table 6.4.[31] Odor, for instance, can be detected in a 1-sec whiff.[32] On the other hand, a much longer exposure to CO

TABLE 6.4. RELATIONSHIP BETWEEN AIR POLLUTANT EXPOSURE AND EFFECTS

| Approximate exposure duration | Effect | Pollutant | | | |
|---|---|---|---|---|---|
| | | Carbon monoxide | Oxidant | Particulate matter | Sulfur oxides |
| 1 sec | Sensation | | | | |
| | Odor | — | x | — | x |
| | Taste | — | — | — | x |
| | Eye irritation | — | x | — | — |
| 1 hr | Student athlete performance impaired | — | x | — | — |
| | Visibility reduced | — | x | x | x |
| 8 hr | Judgment impaired | x | — | — | — |
| | Heart patients stressed | x | — | — | — |
| | Vegetation damaged | — | x | — | x |
| 1 day | Health impaired | — | — | x | x |
| | Soiling | — | — | x | — |
| 4 days | Health impaired | — | — | — | x |
| 1 yr | Health impaired | — | — | x | x |
| | Vegetation damaged | — | — | x | x |
| | Corrosion | — | — | x | x |
| | Soiling | — | — | x | — |

Source: Larsen.[31]

is needed to affect man. The degree of effect is indicated by the concentration of CO in the blood, as shown in Figure 6.5.[31] The highest ambient 8-hr average CO concentration for a day agrees very closely with the highest CO concentration expected in a man's bloodstream for that day. The maximum 1-hr ambient value, however, is a poor indicator of expected blood levels, for it fails to show the relatively slow absorption and desorption of CO that occurs over longer periods.

Just as longer CO exposures usually affect man, so do longer pollutant exposures usually injure vegetation. Although plants can be injured by an exposure of less than 1 hr if the concentration of oxidant, $SO_2$, or other toxicant is high enough, because of the pattern of pollutant concentration variation in urban atmospheres, plant injury is usually caused instead by longer average exposures (such as 3 or 8 hr) at lower concentrations.



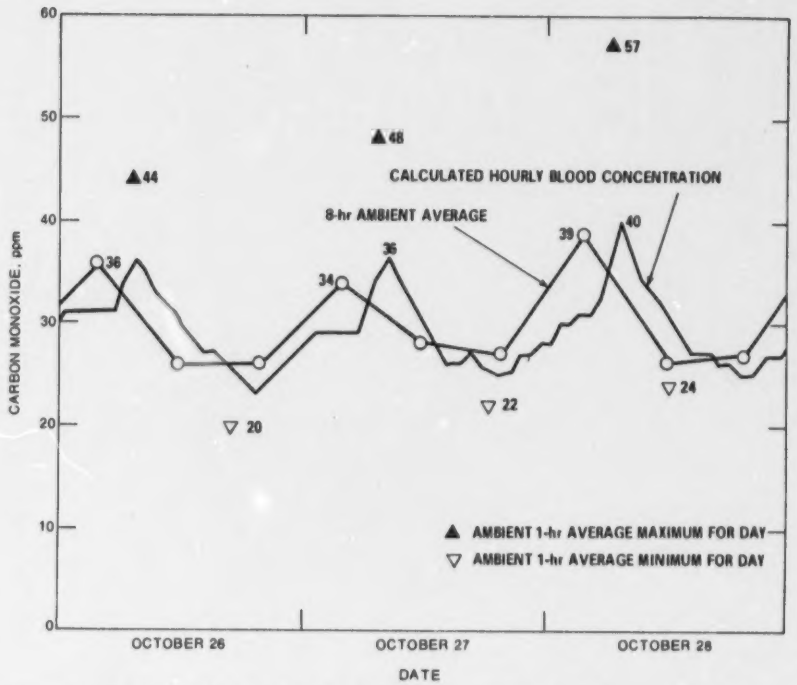


*Fig. 6.5.* Measured ambient air and calculated blood carbon monoxide concentration at the Lennox site in Los Angeles County, 26–28 Oct. 1965. (From Larsen.)[31]

## Air pollutant effects versus frequency

Air pollutant concentrations vary as a function of meteorology and the number, strength, and location of sources relative to a particular air sampling site. The frequency with which a particular pollutant concentration is exceeded determines the frequency with which a particular effect can be expected. For example, the odor threshold concentration for a particular pollutant at a particular location might be exceeded 1 percent of the time. This frequency might not sound very objectionable, but since an odor can be detected in a 1-sec whiff, the odor might be smelled every few minutes.

Similarly, pollutant concentration data can be related to the frequency with which plant injury might be expected. Since commercial crops or ornamental plants can be permanently damaged by one exposure, damage might be expected if a damaging concentration were exceeded even once a year.

In order to relate air quality concentrations to effects, air quality data should be analyzed as a function of both averaging time and frequency.

## Air quality standards

Air quality criteria publications that document air pollution effects (air management Step 1) have been issued by the federal government for CO, hydrocarbons, nitrogen oxides, particulate matter, photochemical oxidants, and sulfur oxides. Similarly, criteria documents have been published under the auspices of the North Atlantic Treaty Organization (NATO).

After seeking a broad spectrum of advice, and operating under federal law, decisions have been reached as to which air pollutant effects to prevent (air management Step 2), and national ambient air quality standards have been established to prevent these effects (Step 3). National primary standards have been set to protect public health, and national secondary standards have been set to protect public welfare (see Table 6.1). States may set ambient standards more stringent than the national standards, if they wish.

Each national standard specifies an averaging time, frequency, and concentration. The averaging times are 1, 3, 8, and 24 hr, and 1 yr. For averaging times of 24 hr or less, the standards are not to be exceeded more frequently than once a year. If the expected annual maximum concentration (expected to occur an average of once a year) is used as the "design" value

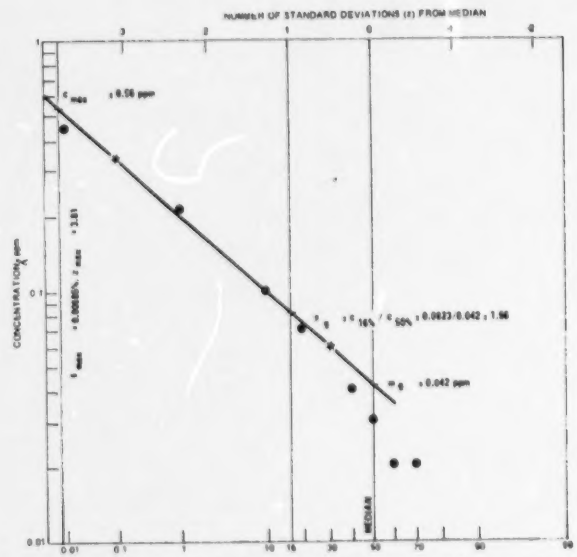


*Fig. 6.6.* Frequency of 1-hr-average sulfur dioxide concentrations equal to or in excess of stated values, Washington, D.C., 1 Dec. 1961–1 Dec. 1968. $c_{max}$ = expected maximum hourly concentration within a year; $m_g$ = geometric mean; $s_g$ = geometric standard deviation. (From Larsen.)[31]



in determining source reductions, then these short-term standards will probably be violated (exceeded more than once a year) in about 1 yr out of 8.[33] Similarly, annual standards will probably be violated in about 1 yr out of 8 if the highest year expected out of 5 is selected as the design value in determining source reductions needed to achieve these annual standards. Use of such design values is recommended.

## Concentration versus averaging times and frequency

An analysis of up to 7 years of continuous concentration measurements of seven gaseous air pollutants in eight cities suggests that the data can be described by an empirical mathematical model with three characteristics:[31,33,34] (a) Pollutant concentrations are lognormally distributed for all averaging times (Fig. 6.6); (b) median (50th percentile) concentrations are proportional to averaging time raised to an exponent (Figs. 6.7 and 6.8); (c) maximum concentrations are approximately inversely proportional to averaging time raised to an exponent.

These graphical data can also be presented digitally in detail (Table 6.5) or in summary (Table 6.6). Computer programs have been written to process air quality data to produce these types of digital and graphical displays.

Techniques, equations, and easy-to-use tables have been developed to calculate expected annual maximum "design" concentrations that can be compared with ambient air standards to determine how much source reduction is needed (air management Step 5) to achieve the standards.[33] If air quality data are available for an averaging time different from an ambient standard, these tables can be used to calculate expected annual maximum design concentrations for the averaging time of the standard.

## Calculating emission reductions

The overall emission reduction needed for an area to achieve an ambient air quality goal or standard can be calculated with a proportional rollback equation. The tacit assumption in this approach is that every source of a particular pollutant is reduced by approximately the same percentage and that the ambient concentration above background is thus also reduced by that percentage. The first application of this approach[35] assumed that no background concentration of the pollutant existed outside of the metropolitan area. The proportional rollback equation has since been altered to allow for background concentrations:[30]

$$R = \frac{gc - q}{gc - b} \cdot 100 \qquad (6.2)$$

where $R$ = the needed reduction, percent,
$g$ = the expected growth factor by some future year,
$c$ = the present design concentration,
$q$ = the air quality goal or standard concentration,
$b$ = the background concentration.

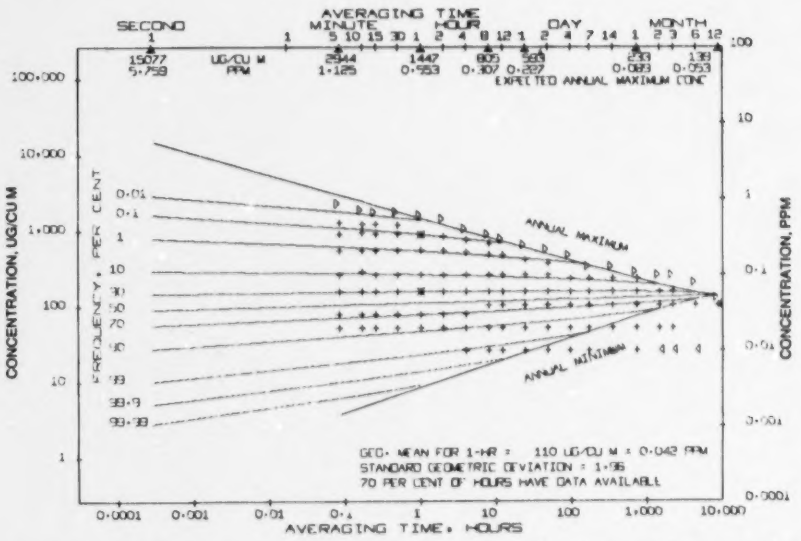


*Fig. 6.7.* Computer plot of concentration versus averaging time and frequency for sulfur dioxide at site 256, Washington, D.C., 1 Dec. 1961–1 Dec. 1968. (From Larsen.)[31]

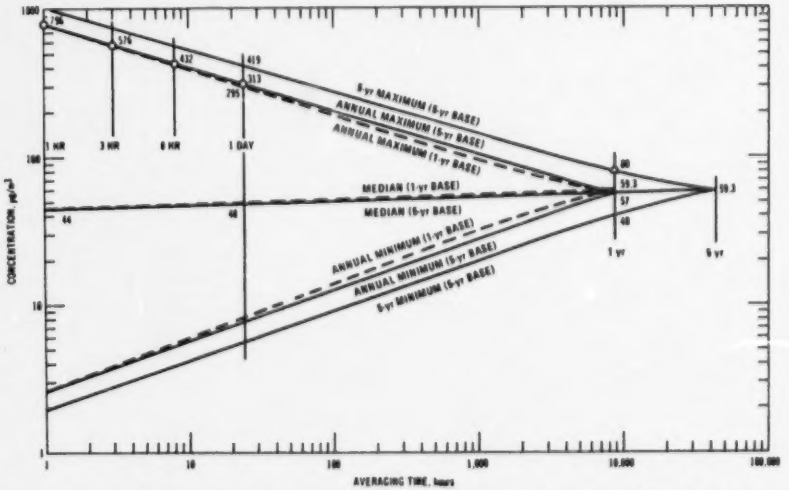


*Fig. 6.8.* Comparison of averaging time model with a 5-yr base (solid lines) with one with a 1-yr base (dashed lines), when standard geometric deviation for 1-hr averages is 2.13 (sulfur dioxide median of the U.S. Environmental Protection Agency's Community Air Monitoring Program [CAMP], and annual maximum hour is 796 $\mu g/m^3$. (From Larsen.)[33]



TABLE 6.5. CONCENTRATION (PPM) VERSUS AVERAGING TIME AND FREQUENCY FOR SULFUR DIOXIDE, WASHINGTON, D.C., 1 DEC. 1961–1 DEC. 1968

| Averaging time | Arithmetic mean | Max. | Min. | Percent data | Percent of time concentration is equaled or exceeded | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.001 | 0.01 | 0.1 | 1 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 99 | 99.9 | 99.99 | 99.999 |
| 5 min | 0.05 | 0.87 | 0.00 | 70 | 0.65 | 0.49 | 0.35 | 0.21 | 0.10 | 0.07 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 0.05 | 0.72 | 0.00 | 70 | 0.66 | 0.47 | 0.36 | 0.21 | 0.11 | 0.08 | 0.06 | 0.04 | 0.03 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 0.05 | 0.68 | 0.00 | 70 | | 0.47 | 0.35 | 0.21 | 0.10 | 0.07 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 30 | 0.05 | 0.68 | 0.00 | 70 | | 0.46 | 0.35 | 0.21 | 0.10 | 0.08 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 1 hr | 0.05 | 0.62 | 0.00 | 70 | 0.45 | 0.34 | 0.21 | 0.10 | 0.07 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 2 | 0.05 | 0.55 | 0.00 | 70 | | 0.32 | 0.21 | 0.10 | 0.08 | 0.06 | 0.04 | 0.03 | 0.03 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | | |
| 4 | 0.05 | 0.41 | 0.00 | 70 | | 0.29 | 0.20 | 0.10 | 0.08 | 0.06 | 0.05 | 0.03 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | | |
| 8 | 0.05 | 0.35 | 0.00 | 71 | | 0.26 | 0.18 | 0.10 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | | |
| 12 | 0.05 | 0.30 | 0.00 | 72 | | 0.25 | 0.18 | 0.10 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | | |
| 1 day | 0.05 | 0.25 | 0.00 | 72 | | | 0.16 | 0.10 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 | | | |
| 2 | 0.05 | 0.22 | 0.00 | 68 | | | 0.14 | 0.10 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 | | | |
| 4 | 0.05 | 0.18 | 0.00 | 71 | | | 0.14 | 0.09 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 | | | |
| 7 | 0.05 | 0.13 | 0.00 | 73 | | | | 0.09 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | | | | |
| 14 | 0.05 | 0.13 | 0.00 | 74 | | | | 0.09 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | | | | |
| 1 mo | 0.05 | 0.11 | 0.00 | 76 | | | | 0.09 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | | | | |
| 2 | 0.04 | 0.10 | 0.01 | 74 | | | | 0.08 | 0.08 | 0.06 | 0.04 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | | | | |
| 3 | 0.05 | 0.10 | 0.01 | 82 | | | | | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | | | | | |
| 6 | 0.04 | 0.08 | 0.01 | 93 | | | | | | 0.06 | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 | | | | | | |
| 1yr | 0.05 | 0.05 | 0.04 | 86 | | | | | | | | | 0.04 | | | | | | | | |

Source: Larsen.[31]

TABLE 6.6. SULFUR DIOXIDE CONCENTRATION (PPM) AT COMMUNITY AIR MONITORING PROGRAM (CAMP) SITES, BY AVERAGING TIME AND FREQUENCY, 1962–68

| City and averaging time | Annual maximum | 1962–68 | | | | Maximum for year | | | | | | | Percent data available | Percent time concentration exceeded | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Geom. mean | SGD[a] | Max. | Min. | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | | 0.01 | 0.1 | 1 | 10 | 30 | 50 | 70 | 90 |
| Chicago | | | | | | | | | | | | | | | | | | | | | |
| 5 min | 3.27 | 0.104 | 2.19 | 1.94 | 1.11 | 1.13 | 1.94 | 1.62 | 1.59 | 1.11 | 1.62 | 1.33 | 83 | 1.31 | 1.01 | 0.67 | 0.32 | 0.16 | 0.08 | 0.03 | 0.01 |
| 1 hr | 1.58 | 0.112 | 2.00 | 1.69 | 0.86 | 0.86 | 1.69 | 1.12 | 1.14 | 0.98 | 1.11 | 0.91 | 83 | 1.11 | 0.95 | 0.64 | 0.32 | 0.16 | 0.08 | 0.03 | 0.01 |
| 8 hr | 0.86 | 0.118 | 1.84 | 1.02 | 0.45 | 0.45 | 0.87 | 1.02 | 0.74 | 0.63 | 0.80 | 0.63 | 84 | | 0.74 | 0.56 | 0.31 | 0.16 | 0.09 | 0.04 | 0.01 |
| 1 day | 0.63 | 0.121 | 1.75 | 0.79 | 0.36 | 0.36 | 0.71 | 0.79 | 0.55 | 0.48 | 0.65 | 0.51 | 86 | | | 0.49 | 0.30 | 0.16 | 0.09 | 0.05 | 0.02 |
| 1 mo | 0.24 | 0.133 | 1.44 | 0.35 | 0.18 | 0.18 | 0.33 | 0.35 | 0.27 | 0.26 | 0.32 | 0.26 | 94 | | | | 0.27 | 0.18 | 0.09 | 0.06 | 0.03 |
| 1 yr | 0.14 | 0.142 | 1.00 | 0.18 | 0.09 | 0.10 | 0.14 | 0.18 | 0.13 | 0.09 | 0.12 | 0.12 | 100 | | | | | | 0.12 | | |
| Cincinnati | | | | | | | | | | | | | | | | | | | | | |
| 5 min | 1.68 | 0.016 | 2.87 | 1.49 | 0.65 | 0.84 | 0.99 | 0.88 | 1.15 | 0.70 | 0.65 | 1.49 | 80 | 0.68 | 0.41 | 0.19 | 0.06 | 0.03 | 0.02 | 0.01 | 0.00 |
| 1 hr | 0.65 | 0.018 | 2.54 | 0.57 | 0.38 | 0.46 | 0.48 | 0.55 | 0.57 | 0.41 | 0.42 | 0.38 | 80 | 0.53 | 0.33 | 0.16 | 0.06 | 0.03 | 0.02 | 0.01 | 0.00 |
| 8 hr | 0.30 | 0.020 | 2.27 | 0.38 | 0.14 | 0.14 | 0.23 | 0.27 | 0.38 | 0.18 | 0.18 | 0.18 | 81 | | 0.22 | 0.12 | 0.06 | 0.03 | 0.02 | 0.01 | 0.00 |
| 1 day | 0.20 | 0.022 | 2.12 | 0.18 | 0.08 | 0.11 | 0.11 | 0.14 | 0.18 | 0.10 | 0.13 | 0.03 | 82 | | | 0.10 | 0.06 | 0.04 | 0.03 | 0.02 | 0.01 |
| 1 mo | 0.06 | 0.025 | 1.63 | 0.06 | 0.03 | 0.04 | 0.06 | 0.06 | 0.06 | 0.05 | 0.04 | 0.03 | 86 | | | | 0.05 | 0.03 | 0.03 | 0.02 | 0.01 |
| 1 yr | 0.03 | 0.029 | 1.00 | 0.04 | 0.02 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.02 | 0.02 | 100 | | | | | | 0.03 | | |
| Denver | | | | | | | | | | | | | | | | | | | | | |
| 5 min | 0.47 | 0.013 | 2.28 | 1.81 | 0.33 | | | | 0.95 | 0.96 | 0.33 | 1.81 | 78 | 0.38 | 0.18 | 0.08 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1 hr | 0.22 | 0.014 | 2.07 | 0.36 | 0.17 | | | | 0.36 | 0.26 | 0.17 | 0.24 | 78 | 0.26 | 0.13 | 0.07 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 |
| 8 hr | 0.12 | 0.015 | 1.90 | 0.14 | 0.05 | | | | 0.14 | 0.10 | 0.05 | 0.10 | 79 | | 0.10 | 0.05 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1 day | 0.09 | 0.015 | 1.80 | 0.07 | 0.02 | | | | 0.06 | 0.05 | 0.02 | 0.07 | 81 | | | 0.04 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1 mo | 0.03 | 0.017 | 1.46 | 0.03 | 0.01 | | | | 0.03 | 0.02 | 0.01 | 0.03 | 83 | | | | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 |
| 1 yr | 0.02 | 0.018 | 1.00 | 0.02 | 0.01 | | | | 0.02 | 0.01 | | 0.01 | 100 | | | | | | 0.01 | | |
| Los Angeles | | | | | | | | | | | | | | | | | | | | | |
| 5 min | 0.47 | 0.013 | 2.28 | 0.68 | 0.24 | 0.24 | 0.51 | 0.68 | | | | | 59 | 0.38 | 0.15 | 0.08 | 0.04 | 0.02 | 0.01 | 0.01 | 0.00 |
| 1 hr | 0.22 | 0.014 | 2.07 | 0.29 | 0.13 | 0.13 | 0.19 | 0.29 | | | | | 67 | 0.25 | 0.13 | 0.08 | 0.04 | 0.02 | 0.01 | 0.01 | 0.00 |
| 8 hr | 0.12 | 0.015 | 1.90 | 0.13 | 0.08 | 0.08 | 0.09 | 0.13 | | | | | 71 | | 0.10 | 0.07 | 0.04 | 0.02 | 0.02 | 0.01 | 0.00 |
| 1 day | 0.09 | 0.015 | 1.80 | 0.10 | 0.06 | 0.06 | 0.07 | 0.10 | | | | | 71 | | | 0.06 | 0.04 | 0.02 | 0.02 | 0.01 | 0.00 |
| 1 mo | 0.03 | 0.017 | 1.46 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | | | | | 64 | | | | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |
| 1 yr | 0.02 | 0.018 | 1.00 | 0.02 | 0.02 | 0.02 | 0.02 | | | | | | 67 | | | | | | 0.02 | | |
| Philadelphia | | | | | | | | | | | | | | | | | | | | | |
| 5 min | 2.67 | 0.055 | 2.41 | 1.25 | 0.79 | 1.25 | 1.05 | 1.00 | 1.11 | 0.79 | 1.12 | 1.10 | 77 | 0.96 | 0.72 | 0.48 | 0.20 | 0.09 | 0.05 | 0.03 | 0.01 |
| 1 hr | 1.19 | 0.060 | 2.18 | 1.03 | 0.66 | 1.03 | 0.85 | 0.84 | 0.94 | 0.66 | 0.77 | 0.88 | 78 | 0.85 | 0.67 | 0.45 | 0.20 | 0.09 | 0.05 | 0.03 | 0.01 |
| 8 hr | 0.61 | 0.064 | 1.99 | 0.71 | 0.43 | 0.56 | 0.58 | 0.54 | 0.71 | 0.43 | 0.56 | 0.55 | 79 | | 0.52 | 0.37 | 0.19 | 0.10 | 0.06 | 0.04 | 0.01 |
| 1 day | 0.43 | 0.067 | 1.88 | 0.46 | 0.35 | 0.35 | 0.46 | 0.43 | 0.35 | 0.36 | 0.35 | 0.36 | 81 | | | 0.31 | 0.17 | 0.10 | 0.07 | 0.04 | 0.02 |
| 1 mo | 0.15 | 0.075 | 1.50 | 0.16 | 0.12 | 0.13 | 0.12 | 0.15 | 0.13 | 0.13 | 0.13 | 0.16 | 88 | | | | 0.12 | 0.10 | 0.08 | 0.07 | 0.04 |
| 1 yr | 0.08 | 0.081 | 1.00 | 0.10 | 0.06 | 0.09 | 0.06 | 0.09 | 0.08 | 0.09 | 0.10 | 0.08 | 100 | | | | | | 0.08 | | |
| St. Louis | | | | | | | | | | | | | | | | | | | | | |
| 5 min | 2.32 | 0.028 | 2.72 | 1.42 | 0.85 | | | 1.16 | 1.42 | 1.25 | 0.85 | 1.33 | 83 | 0.94 | 0.56 | 0.28 | 0.10 | 0.04 | 0.02 | 0.01 | 0.00 |
| 1 hr | 0.94 | 0.032 | 2.43 | 0.96 | 0.55 | | | 0.73 | 0.96 | 0.84 | 0.55 | 0.68 | 83 | 0.73 | 0.49 | 0.25 | 0.10 | 0.05 | 0.02 | 0.01 | 0.00 |
| 8 hr | 0.44 | 0.034 | 2.18 | 0.36 | 0.23 | | | 0.31 | 0.36 | 0.33 | 0.24 | 0.23 | 84 | | 0.29 | 0.18 | 0.09 | 0.05 | 0.03 | 0.02 | 0.00 |
| 1 day | 0.30 | 0.036 | 2.05 | 0.26 | 0.16 | | | 0.26 | 0.19 | 0.18 | 0.21 | 0.16 | 86 | | | 0.14 | 0.08 | 0.05 | 0.03 | 0.02 | 0.01 |
| 1 mo | 0.09 | 0.042 | 1.59 | 0.08 | 0.05 | | | 0.08 | 0.06 | 0.06 | 0.05 | 0.06 | 90 | | | | 0.06 | 0.05 | 0.04 | 0.03 | 0.01 |
| 1 yr | 0.05 | 0.047 | 1.00 | 0.06 | 0.03 | | | 0.06 | 0.05 | 0.04 | 0.03 | 0.03 | 100 | | | | | | 0.03 | | |
| San Francisco | | | | | | | | | | | | | | | | | | | | | |
| 5 min | 0.56 | 0.005 | 2.87 | 0.33 | 0.16 | 0.16 | 0.33 | 0.26 | | | | | 64 | 0.18 | 0.13 | 0.07 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 |
| 1 hr | 0.22 | 0.006 | 2.54 | 0.26 | 0.11 | 0.11 | 0.26 | 0.16 | | | | | 64 | 0.16 | 0.11 | 0.07 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 |
| 8 hr | 0.10 | 0.007 | 2.27 | 0.10 | 0.06 | 0.06 | 0.07 | 0.10 | | | | | 65 | | 0.09 | 0.06 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1 day | 0.07 | 0.007 | 2.12 | 0.08 | 0.05 | 0.05 | 0.05 | 0.08 | | | | | 65 | | | 0.05 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1 mo | 0.02 | 0.008 | 1.63 | 0.03 | 0.01 | 0.01 | 0.02 | 0.03 | | | | | 75 | | | | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 |
| 1 yr | 0.01 | 0.010 | 1.00 | 0.02 | 0.01 | | 0.01 | 0.02 | | | | | 67 | | | | | | 0.01 | | |
| Washington | | | | | | | | | | | | | | | | | | | | | |
| 5 min | 1.14 | 0.040 | 2.14 | 0.87 | 0.42 | 0.42 | 0.56 | 0.87 | 0.44 | 0.47 | 0.44 | 0.53 | 70 | 0.49 | 0.35 | 0.21 | 0.10 | 0.06 | 0.03 | 0.02 | 0.00 |
| 1 hr | 0.56 | 0.042 | 1.96 | 0.62 | 0.35 | 0.38 | 0.48 | 0.62 | 0.35 | 0.45 | 0.37 | 0.42 | 70 | 0.45 | 0.34 | 0.21 | 0.10 | 0.06 | 0.03 | 0.02 | 0.00 |
| 8 hr | 0.31 | 0.045 | 1.81 | 0.35 | 0.22 | 0.23 | 0.35 | 0.32 | 0.27 | 0.34 | 0.22 | 0.22 | 71 | | 0.26 | 0.18 | 0.10 | 0.06 | 0.04 | 0.02 | 0.01 |
| 1 day | 0.23 | 0.046 | 1.72 | 0.25 | 0.15 | 0.18 | 0.25 | 0.22 | 0.20 | 0.25 | 0.15 | 0.18 | 72 | | | 0.16 | 0.10 | 0.06 | 0.04 | 0.02 | 0.01 |
| 1 mo | 0.09 | 0.050 | 1.42 | 0.11 | 0.07 | 0.10 | 0.11 | 0.09 | 0.08 | 0.10 | 0.07 | 0.10 | 76 | | | | 0.09 | 0.06 | 0.04 | 0.02 | 0.01 |
| 1 yr | 0.05 | 0.053 | 1.00 | 0.05 | 0.04 | 0.05 | 0.05 | 0.04 | 0.05 | 0.04 | | 0.04 | 86 | | | | | | 0.04 | | |

[a]Standard geometric deviation.

Source: Larsen.[31]

The above equation is especially helpful when one is considering a pollutant that comes mostly from one source type, such as CO from motor vehicles. Or if CO were to be reduced by the same percentage from both mobile sources and from stationary sources that were important in a particular region, then the equation would still be pertinent.

If emissions from various source types in an area are to be reduced by differing percentages, then meteorological diffusion approaches[36,37] can be used to calculate the expected annual maximum design concentrations at various points in a city as various source control strategies are tested (air management Step 7). Air management Steps 8, 9, 10, and 11 can then be taken to set and enforce emission standards. Step 12 can be taken to ensure that sources are reduced and that air quality goals or standards are continuously achieved. As the number or strength of emission sources grows after they initially have been controlled, Steps 4–12 can be repeated to ensure that ambient air quality standards are continuously achieved.

## Interpretation and Use of Air Quality Data

The goal of achieving clean, acceptable air quality was enhanced by passage of the Clean Air Act Amendments of 1970. The act specifies that the states must develop comprehensive implementation plans whereby pollutant emissions within designated Air Quality Control Regions are sufficiently controlled to achieve federally designated National Ambient Air Quality Standards. At the heart of this act is the philosophy that air quality can be managed and controlled by a carefully designed process of emission regulation and abatement. The authors of the act favored this approach over uniform national emission control for all sources, because of the economies gained by demanding the greatest degree of control on sources near which the air quality problem is most severe.

The fundamental requirement in the design of an emission control strategy to achieve any ambient concentration goal is the air quality/emission relationship. This relationship, which is generally specific to a particular area, is critical in the development of an acceptable plan for achieving the ambient standards. Such a relationship is usually expressed mathematically and is termed a "model." It is the primary tool through which ambient air quality data estimations or predictions are made. Ideally, such a model or relationship can be used to infer the air quality pattern that would result for each of a number of candidate emission-control plans. In this manner, the air quality planner can choose the most cost-effective plan that would achieve the NAAQS.

### Models for air quality planning

#### *Rollback model*

Perhaps the simplest model and the one most widely used by air pollution control agencies for planning purposes is the proportional rollback model. This is based on the assumption that if all sources of a pollutant are reduced by about the same proportion, then ambient concentrations above background will be reduced by the same proportion:

$$C_i = b + Ke \tag{6.3}$$

where $C_i$ = ambient concentration of the pollutant in question at the $i^{th}$ receptor,
$b$ = background concentration,
$K$ = proportionality constant between emission rate and concentration,
$e$ = total emission rate of all emitters within a defined geographical area.

This model of air quality may be used to develop a design emission rate that would be compatible with the achievement of an air quality standard. By considering emission growth, this simple air quality/emission relationship leads to the familiar proportional rollback model[38,39] that was mentioned in the previous section (Equation 6.2).

Although this model is highly simplistic, a sizable quantity of data is required for its utilization. These data requirements include an emission inventory, which gives the emission rate for each source or each source type within the defined area, and the air quality monitoring data measured during the same time interval for which the emission estimates were obtained. Additionally, background air quality and an estimate of expected growth within the region to be controlled are required.

The rollback model is inadequate in several major respects. Most serious of these deficiencies are the assumptions that either (a) all classes of sources have the same spatial and temporal distribution of emissions so that reductions in one class of emissions will have the same effect on air quality as a similar emission reduction in any other source-emission category, or (b) all sources are controlled by the same proportion. The rollback model would obviously be less reliable in situations where emissions from remote sources were controlled in disproportion to the control of nearby sources.

#### *Modified rollback*

To overcome the above problem, more advanced rollback models have been employed. The most recent of these is the modified or improved rollback model,[39] which is expanded to include the air quality impact of each source or source category. The source impact depends, in general, on the distance and spatial orientation between the source and monitoring sites.

The simple proportional model given in Equation 6.3 then becomes

$$C_i = b + \sum_{j=1}^{N} K_{ij} e_j \tag{6.4}$$

where $C_i$ = ambient concentration at receptor $i$,
$b$ = background concentration,
$N$ = number of source categories,
$K_{ij}$ = source-receptor contribution for source category $j$ to receptor $i$,
$e_j$ = emission rate for source category $j$.